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# NASA'S ROLE IN AERONAUTICS: A Workshop

## Volume V Rotorcraft

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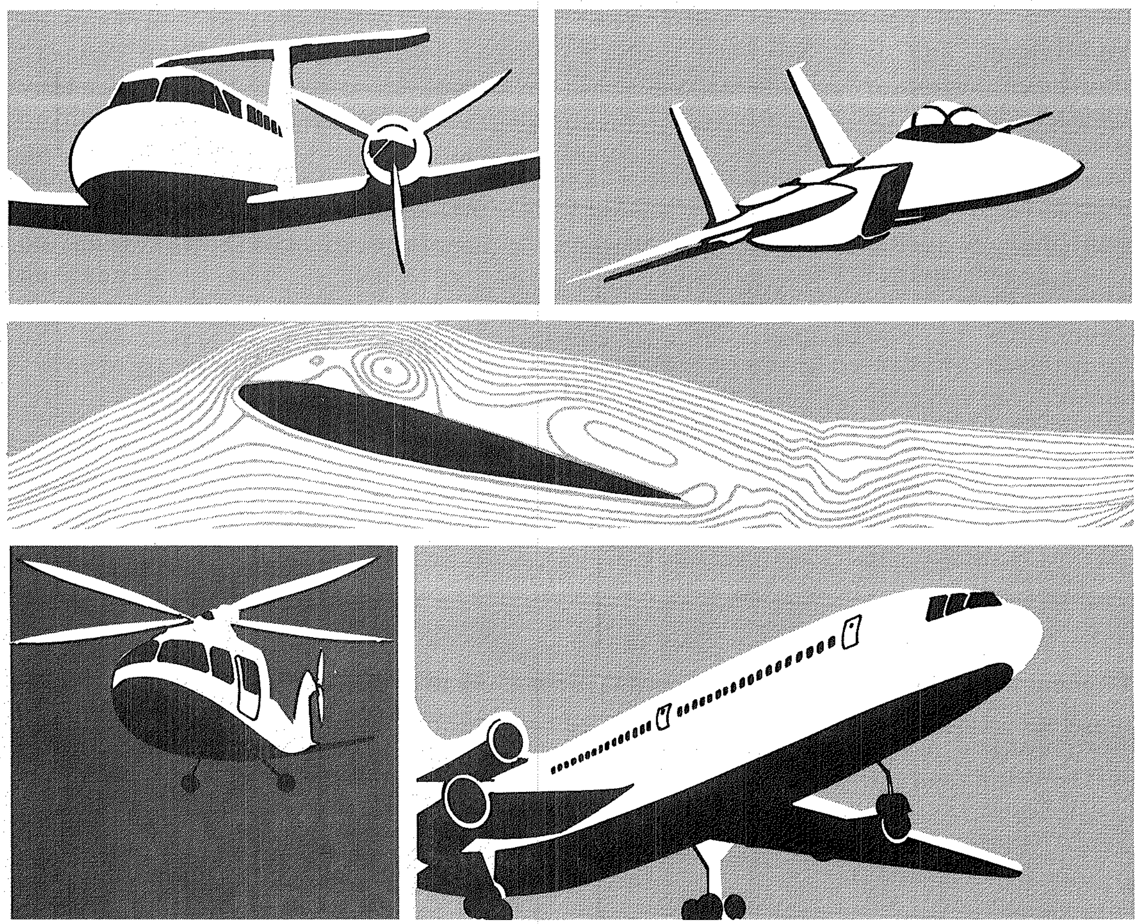

Report to the Workshop by the Panel on Rotorcraft
Aeronautics and Space Engineering Board
Assembly of Engineering
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Aeronautics and Space Engineering Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

WORKSHOP ON
THE ROLE OF NASA IN AERONAUTICS

ROTORCRAFT PANEL

Edward S. Carter, Chairman
Director of Technology
Sikorsky Aircraft Division
United Technologies Corporation

Holt Ashley
Professor, Department of Aeronautics and Astronautics
Stanford University

Richard L. Ballard
Chief, Technology Support Team
Aviation Systems Division
Department of the Army

B. Paul Blasingame
Retired Manager, Santa Barbara Operations
Delco Electronics Division
General Motors Corporation

Arnold Brooks
Manager, Advanced Engineering Program
General Electric Company

Glen A. Gilbert
Glen A. Gilbert Associates

Harlan S. Hosler
Chairman, Helicopter Operation Task Forces
Office of Aviation Safety
Federal Aviation Administration

John Kerr
Vice President, Engineering, Research and Development
Hughes Helicopters
Division-Summa Corporation

Stanley Martin
Director, Advanced Product Design and Development
Bell Helicopter Textron

James R. Nelson
Chief, Helicopter Systems Branch
Federal Aviation Administration

William Walls
Director of Technology
Boeing Vertol
The Boeing Company

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# P R E F A C E

Aeronautics is changing in many significant respects. The implications of this are so far-reaching as to call into question the future position of the United States in world aviation.

The magnitude of this question, with its possible consequences for the nation's economy and security, led the National Aeronautics and Space Administration (NASA) to seek an independent evaluation from the Aeronautics and Space Engineering Board (ASEB) of the National Research Council's Assembly of Engineering. Specifically, the ASEB was asked to assess the nature and implications of the current state of U.S. aviation in a world setting and their significance for NASA's role in the nation's aeronautical future.

The ASEB responded by convening a workshop July 27 through August 2, 1980, at the National Academy of Sciences' Woods Hole Study Center. The workshop was structured into four panels covering military aviation, transport aircraft, general aviation, and rotorcraft. In addition, an overview panel was formed to consider NASA's role in research as well as its relationships with other elements of the aeronautics community.

The central task of the workshop was to examine the relationship of NASA's aeronautical research capabilities to the state of U.S. aviation and to make recommendations about NASA's future roles in aeronautics.

NASA and its predecessor, the National Advisory Committee for Aeronautics (NACA), traditionally have maintained a cooperative relationship with the aeronautical industry, with other government agencies concerned with aircraft operations and regulations, and with the academic community engaged in aerospace research. This triumvirate was taken into account in planning the workshop and selecting the participants. Thus, representatives from each part of the aeronautical community were invited, and information on NASA's relationship with each was the subject of special presentations prior to the working sessions. Representation from industry was predominant because industry's relationship with NASA is considered to be a key element in examining the present and future roles of NASA.

The members of the workshop panels represented, in total expertise and experience, all of the important sectors of aeronautics: military aircraft and missiles; commercial air transports; general aviation;

rotorcraft; university and private research; airline operations; and government regulatory agencies. In addition, the participants also included representatives of other industries--notably, automotive, electronics, and steel. Including the speakers and other nonpanel members, close to 80 individuals participated.

The participants were asked to address the issue of NASA's role in the context of a wider discussion concerning: the status and dimensions of U.S. aeronautics; the key aeronautical problems and opportunities that are likely to be amenable to research and technology development; the historical evolution and accomplishments of NASA in aeronautical research and technology development; and possible alternatives to NASA. Each of these subjects is discussed thoroughly in separate panel reports.

The report of the workshop consists of seven volumes:

I -- Summary

II -- Report of the Panel on Military Aviation

III -- Report of the Panel on Transport Aircraft

IV -- Report of the Panel on General Aviation

V -- Report of the Panel on Rotorcraft

VI -- Report of the Overview Panel on Aeronautical Research

VII -- Background Papers--The Outlook for Aeronautics and Relevant Areas

In order to help focus the discussion, NASA officials developed and provided a concise set of definitions of eight possible roles for NASA: <u>National Facilities and Expertise</u>; <u>Research</u>; <u>Generic Technology Evolution</u>; <u>Vehicle Class Technology Evolution</u>; <u>Technology Demonstration</u>; <u>Technology Validation</u>; <u>Prototype Development</u>; and, <u>Operations Feasibility</u>. Because some of these roles differ, depending on the aeronautical discipline involved, the roles are assessed within six principal aeronautical disciplines: <u>aerodynamics</u>, <u>structures and materials</u>, <u>propulsion</u>, <u>electronics and avionics</u>, <u>vehicle operations</u>, and <u>human engineering</u>. Definitions of these roles and disciplines are contained in Appendix A. The matching of the roles and disciplines is treated in Volumes II-VI and summarized in Section II of Volume I.

The workshop participants were extensively briefed by officials from NASA, the Department of Defense (DOD), and the Federal Aviation Administration (FAA), by leaders from the aviation manufacturing and operating industries, and by a member of Congress. The briefings are to be found in Volume VII.

Each panel separately considered the national benefits produced within the dimensions of its sector and the relative state of the sector's world position; each considered the evolution of NASA's role,

as well as a rationale for NASA's aeronautical support of its sector; and, finally, each panel produced sector-oriented conclusions and recommendations for NASA's roles for the future. Although there are obvious overlaps, the similarities and differences in each of the panels' findings are preserved in the separate reports of the sector-oriented panels, Volumes II-V.

This document, Volume V, presents the findings and recommendations of the Panel on Rotorcraft.

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## INTRODUCTION

The commonality of concerns for rotorcraft and the rest of the aeronautical technologies is apparent in some of the other panel reports. Beyond this, rotorcraft are different from the rest in a number of ways, which shape the rotorcraft community's perception of NASA's role in aeronautics in several respects. The factors that tend to set rotorcraft apart include the following:

- The technology is extremely complex. Until now, the complexity of the dynamic and aerodynamic problems faced by rotorcraft designers has forestalled numerical analysis in any total sense. Such analysis involves a large number of dynamic degrees of freedom and an extremely intricate set of aerodynamic interactions. Only recently, with the advent of powerful high-speed computers, has it become feasible to attempt an analysis of the whole problem.

- System-level demonstrations play a larger role in the rotorcraft program. In rotorcraft there is a close interaction among the dynamic, aerodynamic, and aeroacoustic elements of the problems. Thus, new solutions and concepts must be demonstrated almost always at the systems level before their value can be established.

- Rotorcraft technology is relatively immature, so the opportunities for progress are very great. In the past, the resources for rotorcraft technology development allocated by both government and industry have represented only a small fraction of those allocated to more conventional elements of the aircraft industry. Consequently, with far more difficult problems to solve and far fewer resources for the attack, much of rotorcraft technology remains an empirical "black art" rather than a practical science. Rotorcraft technology is 20 to 30 years behind that of fixed-wing aircraft. As a result, it stands to reason that enormous improvements in rotorcraft efficiency and comfort can still be achieved.

o <u>The European aircraft industry has been more competitive in rotorcraft than in other fields of aeronautics</u>. Since a high technology approach to rotorcraft design has only become possible recently, European industry has been able to parallel U. S. efforts easily. Already, the total employment of the European industry closely approximates that of the United States. Foreign competition in the world rotorcraft market has been significant. Moreover, foreign rotorcraft have been matching U.S. rotorcraft in highly visible ways for some time. Both French and Soviet designs have alternated with U.S. designs in achieving world speed records. The Soviet Union currently holds the record with its HIND D. Furthermore, although U.S. research facilities for rotorcraft are generally superior to those in the rest of the world, Europeans are developing more advanced facilities to deal with such problems as noise and icing research in special wind tunnels.

o <u>The divergence of civil and military requirements has begun to affect the rotorcraft market only recently</u>. The rotorcraft industry traditionally has depended upon derivatives of military designs to meet civil requirements. Now, however, military aircraft have become so specialized that they are no longer suitable as a basis for competitive civil designs in the small and medium classes. Table 1 illustrates this problem. Rotorcraft to meet such civil sector needs as the provision of certain public services can no longer depend on further improvements in technology developed for military purposes.

TABLE 1 Black Hawk

| Military Attributes | Civil Market Penalty |
|---|---|
| • Threat Survivability | • Weight<br>Irrelevant Features |
| • Rapid Maneuverability | • Excessive Installed Power<br>Optimized for Low Speed |
| • World Wide Capability | • Excessive Installed Power<br>Dynamics-Heavy Design |
| • Ease of Air Transportation | • Design Constrained<br>Cabin Size Unacceptable |
| • Reliability and Maintainability | • None |
| • Crashworthiness | • None |

o <u>Noise is a greater problem for rotorcraft than for fixed-wing aircraft</u>. By the very nature of their missions, rotorcraft operate nearer clusters of population. Thus, acceptable noise levels become a critical factor for rotorcraft. While new Federal Aviation Administration ruling on reducing rotorcraft noise to acceptable levels is considered imminent, the manufacturers claim that the current technology base for meeting the requirement is far from adequate without a significant economic sacrifice. Research is urgently needed to bring the

rotorcraft state-of-the-art to the point at which fixed-wing aircraft stood when noise rules were implemented for those aircraft.

- Although the social benefits of rotorcraft are hard to measure, they appear to be unique. The applications of rotorcraft are more varied than that of any other aircraft. Thus, the rationale for rotorcraft research and development can be based on grounds other than transportation and defense. These benefits of rotorcraft are discussed in greater depth in the next section.

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# STATUS AND DIMENSIONS OF THE ROTORCRAFT SECTOR OF THE AVIATION COMMUNITY

The dimensions of the rotorcraft sector of the U. S. aviation community can be measured in several ways. In number of employees, the major U.S. helicopter companies are relatively small compared to the U.S. fixed-wing companies. The four major U. S. manufacturers--Bell, Sikorsky, Boeing Vertol, and Hughes--employ approximately 28,000 people, while their European counterparts--Aerospatiale (France), Westland (U.K.), Agusta (Italy), and MBB (West Germany)--employ about 25,000[1]. To the extent that the number of employees is indicative of production capacity and product development resources, the European companies are strong competition for the U.S. rotorcraft industry.

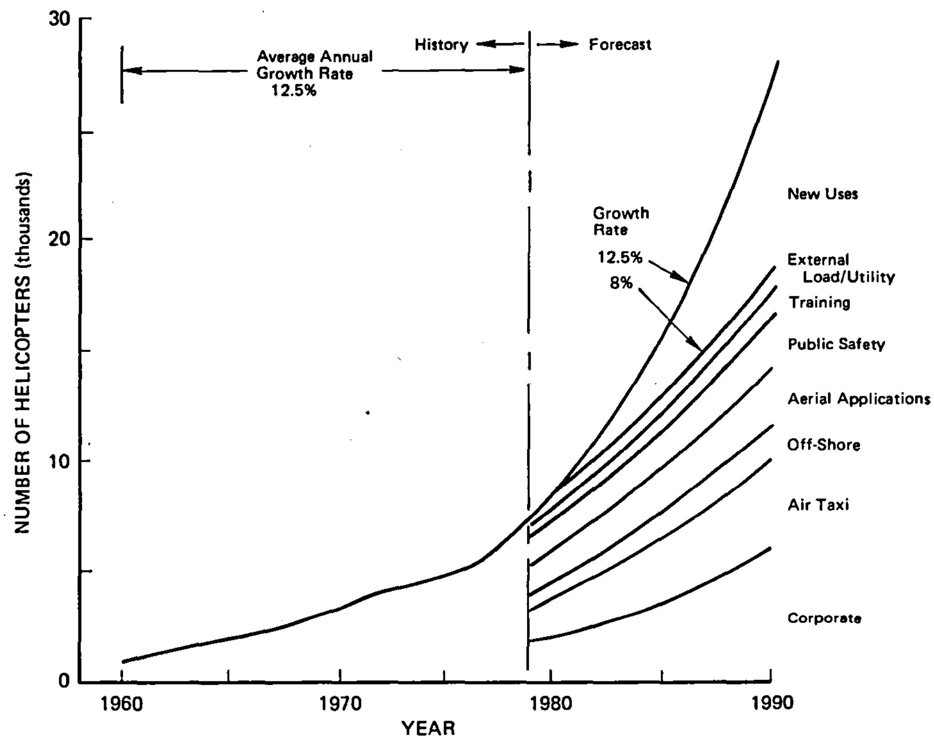
## Military Usage

Despite its relatively small size in comparison with the fixed-wing aircraft industry, the U.S. rotorcraft industry has provided a majority of the aircraft bought by the Department of Defense. More than half of the 29,836 aircraft procured for the U.S. military between FY 66 to FY 79 were helicopters. These statistics are admittedly influenced by the large number of helicopters procured to support the U.S. military in Vietnam, but this does not diminish their importance. Rather, it points up the fact, suggested also by the earlier Korean conflict, that helicopters are vital in the type of limited conflict that the U.S. has had to address. With each conflict the need for greater capability and sophistication has been clear. The role of helicopters, as envisioned by military planners, will continue to expand, especially as the new generation of helicopters developed in the 1980s becomes operational.

## The Civil Market

Based on historical trends and recent market surveys it is possible to predict the status of the U.S. rotorcraft industry at the end of this decade. Figure 1 shows that the market for civil helicopters in the U.S. and Canada has grown steadily from 1960 through 1979 and projects additional growth through 1990.[2] Two growth rates are indicated: an 8 percent rate, which is based only on the expansion of

existing markets, and a 12.5 percent rate, which is based on average annual growth during the last two decades. The higher rate might be anticipated if rotorcraft continue to find new markets as they have in the past. Regardless of which growth rate is assumed, the number of helicopters operating in the civil market in the U.S. and Canada will more than double by 1990.




Source: Aeronautics and Astronautics, Nov. 1979, Technical Challenges in Developing the New Wave of Small and Medium Helicopters, James A. Atkins.

FIGURE 1 Growth Forecast-Light & Medium Helicopters United States and Canada

In a 1975, forecast of the world helicopter market, Aerospatiale estimated that 27,000 helicopters would be sold in the 10 years to 1985. Of these, 13,000 would be sold in North America (all assumed to be commercial).[3] This corresponds with the 12.5 percent growth rate in helicopters projected in Figure 1 for the same period.

## World Market Projections

Two U.S. companies, Bell Helicopter Textron and Sikorsky Aircraft, independently have estimated the world helicopter market for the decade

of the 1980s. Bell reckons on a market of 26,000 units with a total value of $21 billion[4] and Sikorsky, 29,000 units worth $29 billion.[5]

The range of estimates from $21 to $29 billion represents only part of the total market in the decade. Past experience shows that during the seven-to-ten year flight life of a helicopter it is likely to require maintenance and support services that double the value of the initial procurement costs. If this ratio prevails during the 1990s, helicopter sales during the decade will range from $42 to $58 billion. If the same market growth projected for the decade of the 1980s prevails during the decade of the 1990s, the world helicopter market will once again double to about $80 to $120 billion, including support requirements.

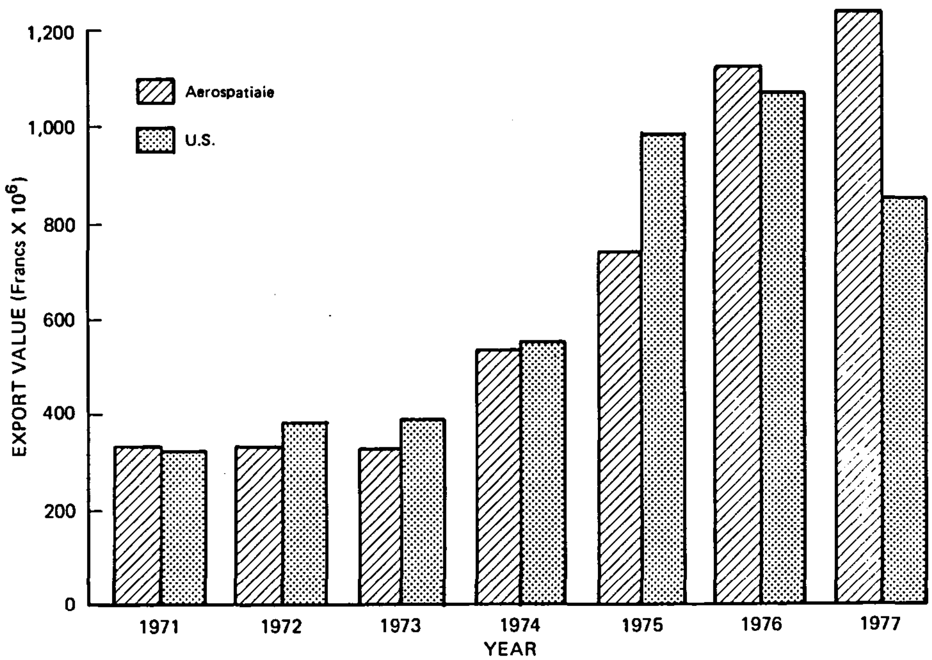
The rationale for such growth projections is straightforward. First, the helicopter is still a technological infant, and, while some of its identifiable markets are increasing rapidly, a significant part of its growth potential is in applications not clearly foreseen. (See Figure 1). Through technological improvements in speed and range, reduced operating costs, and more reliable performance in adverse weather conditions, the helicopter will find new markets in which it can compete economically with existing modes of transportation.

Second, research conducted by NASA indicates that major breakthroughs in rotorcraft performance can be anticipated. The XV-15 tiltrotor, already in the flight demonstration phase, shows promise of providing operational rotorcraft that are capable of flying twice as many passenger miles per gallon of fuel as today's helicopters--at twice today's speed. Similarly, the Advancing Blade Concept (ABC™) research aircraft is demonstrating a simple, direct, and compact solution to the problem of providing high speed and agility while retaining the stationary hover efficiency of the conventional helicopter. Undoubtedly, with a marked improvement in performance, rotorcraft should develop entirely new markets during the 1990s.

## Market Penetration by Foreign Competition

The U.S. share of the world rotorcraft market has declined over the past 10 years. During the five-year period from 1970 to 1974, U.S. companies' share of the sales value of of all helicopters produced in the free world was 68 percent. From 1975 to 1979, the U.S. market share declined to 53 percent.[5] If this trend is not reversed, U.S. manufacturers may soon be selling fewer than half of the helicopters in the international market.

Statistics show why European helicopter manufacturers place great emphasis on export. Aerospatiale forecasts that it can expect only 16 percent of its sales to be in Europe, but 48 percent in the United States, and 36 percent in the rest of the world.[6] The prospects of Aerospatiale's export drive in relation to U.S. sales are illustrated in Figure 2.




Source: Aerospatiaie No. 64 July-August 1976, European Prospects in the Helicopter Field, F. Legrand.

FIGURE 2 Helicopter Export Values

## MAINTAINING A SUPERIOR ROTORCRAFT CAPABILITY

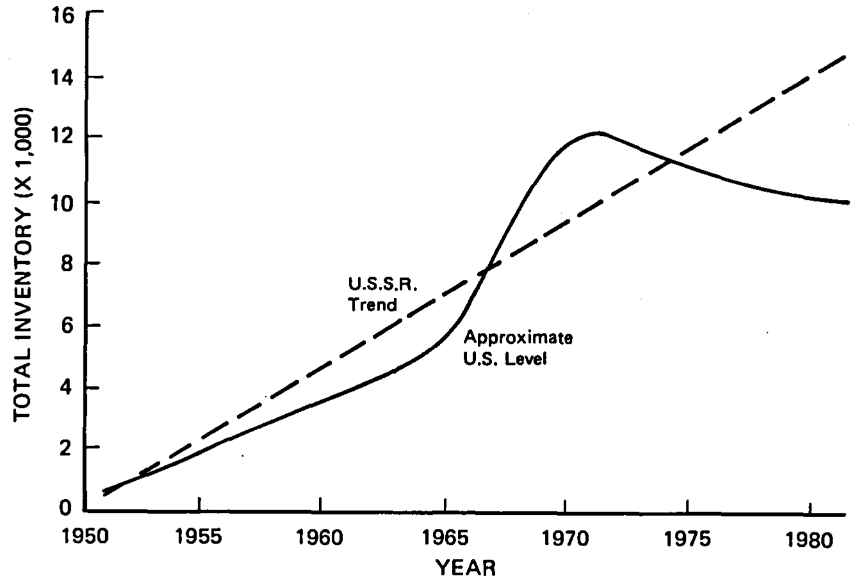
The pressing need for strengthening U.S. defense as well as the market opportunities of rotorcraft are the traditional arguments for augmenting NASA's role in rotorcraft research. Moreover, it is becoming increasingly apparent that advances in rotorcraft technology offer unique benefits to society that provide additional justification for government support at this time.

### Support of National Defense

The realities of the world situation require that the United States offset its numerical inferiority with qualitative superiority in all types of aircraft. This is particularly critical with regard to rotorcraft. The U.S.S.R depends heavily on rotorcraft as a major element of its combat forces. Figure 3 shows the growth trend in the total rotorcraft inventory for the United States and the U.S.S.R. Within this inventory, the U.S.S.R. holds a particularly significant advantage in attack and antitank helicopters. The U.S.S.R. also enjoys a significant numerical superiority in tanks; they have 40,000, while the United States has only 12,000.[7] The ability of the United States to successfully support a land-based confrontation in the NATO theater is a matter of grave concern. The U.S. Army has identified qualitatively superior rotorcraft as a key element in its ground war strategy to counter the quantitive inferiority. In addition, technical options must be available to respond to threats not now clearly defined. During the decade of the 1980s NASA should have a critical role in support of the Department of Defense in this area, and its program must by dynamic, innovative, and large enough to lay a technology base that goes beyond immediately foreseen needs.

### Economic Benefits

Although the total market for rotorcraft is significantly smaller than for fixed-wing aircraft, it is a rapidly growing segment of the U.S. aerospace industry. Continued superiority of U.S. civil rotorcraft, dependent to a large extent on NASA research and technology, could play a critical role in determining the U.S. share of the anti-




Source: Report of *ad hoc* committee convened at the request of the Assistant Secretary of the Army for R,D, & A, June 26, 1980, Vertical Lift Technology Review, N. Augustine, *et al.*

FIGURE 3 Military Rotary Wing Inventory

cipated large market potential.

The major U.S. investment in aeronautical technology during the last several decades, in which NASA played a leading role, is largely responsible for the current world preeminence of the United States in the commercial aircraft and general aviation markets. The same attention to rotorcraft could produce a comparable market response. Figure 4 illustrates the situation.

## Support of Societal Needs

Rotorcraft provide essential support in resource exploration, particularly for offshore oil, and in emergency medical services. Without helicopters, the international oil industry could not exploit effectively its exploration and production activities at the farthest reaches off shore. The movement of personnel and equipment by boats is slow, uneconomic and frequently hazardous. Indeed, one-third of the world's offshore oil supply is dependent on helicopters.

The cost-effectiveness of helicopters in lifesaving operations can be easily substantiated. If one accepts the relatively low societal value of a human life at $200,000, as hypothesized by the National Highway Commission, the investment in the entire world helicopter fleet probably could be justified for its life saving contribution alone.

Many other societal benefits can be foreseen for advanced rotorcraft technology in the future. Some of the missions of rotorcraft,

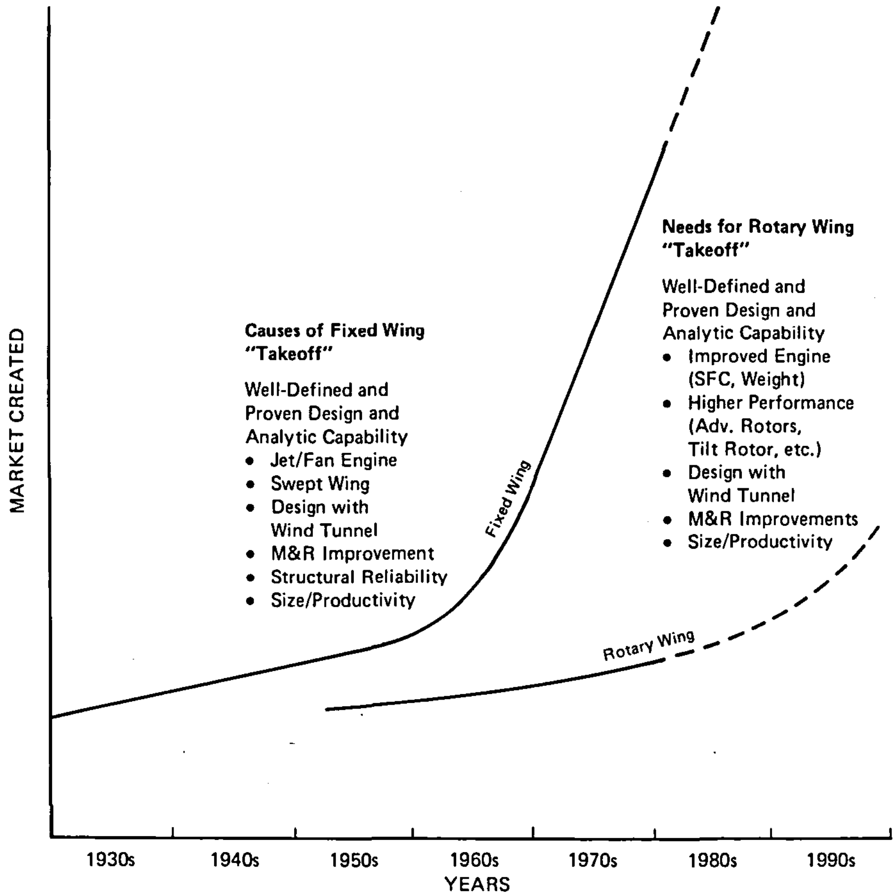



FIGURE 4 What Rotary Wing Aircraft Need to Achieve Industry "Takeoff"

along with the importance and value of the new technology, are listed in Table 2. So, to cite two examples, a 15 percent increase in speed for a standby ambulance helicopter will increase, by more than 30 percent, the area that an emergency medical facility can serve during 15 minute flights and increased range would increase the offshore areas that could be searched for additional oil.

TABLE 2

| Mission | Importance | Value of New Technology |
|---|---|---|
| Resource Development | Currently 33% of world's oil production depends upon rotorcraft | Higher speeds and longer range to go further offshore |
| Disaster Relief | Over 100,000 civilians already saved by world's helicopter fleet | Higher speed and longer range for productivity of faster response time |
| Medevac | Over 900,000 Med-Evac's in Southeast Asia Civilian Med-Evac units showing tremendous Return on Investment (92 documented lives saved by 1 helo in 6 months) | Speed established radius of action and area serviceable (by square of speed) |
| Police Work | Controlled experiments confirm 2 to 6 times apprehension rate with helicopters | Higher speed for faster response. Quieter for more surprise and community acceptance |
| Short Haul/Commuter | Technology of the 1950's struck out: unexplored with new technology: runway congestion will force shift to VTOL | Higher speeds and productivity, better ride comfort, all weather reliability necessary to fully exploit potential benefits |
| Lumbering and Industrial Applications | Very cost effective in specialized role; will expand with greater availability of heavy helicopters and more efficient ferry capability | Exploit greater availability of helicopters developed for other missions above. Twin lift for special situation |
| Executive Transportation | Very fast growing–currently depending on door to door advantage but runway congestion will dictate helicopters for airport (connection) access | Higher speed and better ride comfort to expand market and increase practical range |

## ROTORCRAFT RESEARCH AND TECHNOLOGY NEEDS

The needs for research and development in the rotorcraft field have been thoroughly examined and reported in recent years by the NASA Rotorcraft Task Force[3] and the ASEB ad hoc Committee on Rotorcraft.[8] More recently, the Rotorcraft Subcommittee of the NASA Advisory Committee supplemented the findings of the earlier studies. The conclusions and recommendations of all three groups are still applicable, and the research program developed by the NASA Task Force is generally endorsed by this panel. Table 3 summarizes the current priority research concerns for the 1980s.

TABLE 3 Priority Rotorcraft Research Needs for the 1980s

1. Fundamental understanding of rotor/airframe aerodynamic and dynamic phenomena to improve performance and reduce vibration and noise by development of:
   - Rotor dynamic analysis techniques
   - Airframe dynamic analysis techniques
   - Understanding of dynamic and aerodynamic interaction of airframe and rotors.
2. Noise abatement technology to establish acceptable criteria for new designs and the technology to meet them by development of:
   - Community noise acceptance criteria
   - Component noise prediction methods
   - Vehicle noise prediction methods
   - Design concepts for quieter components and systems.
3. Technology to provide base for as yet unformalized military requirements and to increase civil productivity and usefulness through higher speeds and heavier lifts by:
   - Winged component helicopter investigation using the RSRA
   - Lifting rotor compound helicopter investigation on ABC
   - Tilt rotor technology development using TRRA
   - Propulsion components optimized for compound and tilt rotor aircraft
   - Studies of heavy lift options including multi-lift.
4. Improved operational capability to improve dependability and safety by:
   - Terminal area approach solution equipment for steep gradient, slow approach for:
     - High density terminals
     - Remote and confined area heliports
   - Active control technology for vibration and gust suppression
   - Self contained guidance and control
   - Better cockpit integration and human factors
   - De-icing criteria and certification facilities
   - De-icing solutions.
5. Advanced component technology for more efficient, economical and quieter dynamic component building blocks by development of:
   - Longer life, quieter transmissions
   - Better fuel consumption in small gas turbines.

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# THE EVOLUTION OF NASA'S CURRENT ROLE IN ROTORCRAFT TECHNOLOGY

The evolution of rotorcraft began with the first flight of early experimental helicopters in the late 1920s although sustained flight was not achieved until the late 1930s. Military use of rotorcraft was seriously considered during World War II, but it was not until the Korean conflict in the early 1950s that rotorcraft made a significant military contribution. On the civil side, several pioneering efforts during the late 1940s and early 1950s were not fruitful. In the 1950s and the 1960s, concerted efforts were made to integrate the latest military and civilian rotorcraft technology. This resulted in rapid growth of the civilian helicopter sector in the 1970s. More recently, civil and military requirements have begun to diverge, resulting in a demand for research and development specifically geared either to the civil or to the military markets.

NACA and NASA have made meaningful contributions to rotorcraft development. During the 1930s, the fundamental groundwork for rotor analysis was developed. During the 1940s and 1950s, ground and flight experimental research contributed to a better understanding of flying qualities and to improved performance prediction methods. In the 1960s, as the space program developed, NASA concern with rotorcraft diminished. At the start of the decade of the 1970s, NASA rotorcraft programs began to accelerate and special attention was paid to building up facilities for rotorcraft research. Early emphasis was on basic research, including the development of analytical methods and rudimentary ground and flight research techniques.

Significant organizational changes occurred when Army Laboratories were established at the Ames Research Center in 1965 and at Langley and Lewis in 1970. The joint, coordinated activities of the Army and NASA have improved the effectiveness of both programs and have become models for other cooperative ventures. Specialized test modules were developed for a number of wind tunnels; the Rotor Systems Research Aircraft (RSRA) and the Tilt Rotor Research Aircraft (TRRA) were built; the Vertical Motion Simulator was started; and a major upgrading was initiated for the 40 x 80-foot tunnel to perform full-scale rotor research.

From the 1930s to the late 1960s, the NACA and NASA resources allocated for rotorcraft were modest in relation to the total

aeronautics budget. NASA's commitment to rotorcraft increased with formalization of the cooperative program with the Army. The program helped foster increased funding of rotorcraft research and technology development--from approximately $5 million at the start of the 1970s to approximately $30 million now. An even greater commitment appears warranted during the 1980s to perform research on complex rotorcraft problems and thereby to strengthen the industry in providing improved rotorcraft and staving off increasing foreign competition. Potential future budgets are shown in Figure 5, along with the funding recommended in NASA's 1978 report, Advanced Rotorcraft Technology[4]. This report was extensively reviewed and enthusiastically supported by the rotorcraft industry.

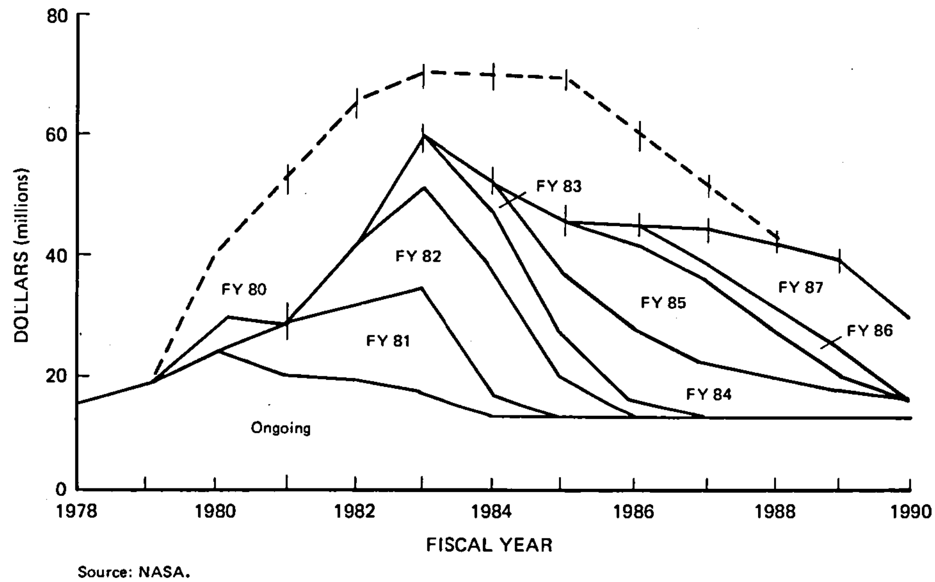


FIGURE 5 NASA Funding Summary for Rotorcraft

In the sections that follow, the panel reviews the potential roles for NASA relating to rotorcraft. NASA's participation is delineated for each role as defined in Appendix A, a rationale is provided, the current level of activity is summarized, and suggestions are given for the kinds of research still needed. The panel's recommendations are summarized in Figure 6.

NASA ROLE CODE:
1. Major Role
*2. Moderate Role
*3. Minor Role
*– No Role

| ROLES / DISCIPLINES | AERODYNAMICS | STRUCTURES & MATERIALS | PROPULSION | ELECTRONICS & AVIONICS | VEHICLE OPERATIONS | HUMAN ENGINEERING | FLIGHT CONTROL | AIRCRAFT SYSTEMS |
|---|---|---|---|---|---|---|---|---|
| NATIONAL FACILITIES & EXPERTISE | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RESEARCH | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| GENERIC TECHNOLOGY EVOLUTION | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| VEHICLE CLASS TECHNOLOGY EVOLUTION | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| TECHNOLOGY DEMONSTRATION | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 |
| TECHNOLOGY VALIDATION | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 2 |
| PROTOTYPE DEVELOPMENT | – | – | – | 3 | 3 | – | 3 | – |
| OPERATIONS FEASIBILITY | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 1 |

*If a proposed project or program initially falls in a recommended moderate, minor, or no-role category, but, following review of its merits on an individual case basis, is deemed to be a desirable undertaking by virtue of its being in the national interest, or mandated by the Congress or as a result of review it is concluded there are other overriding circumstances, then NASA's role for that project or program would be elevated to a major one (i.e., Category 1).

FIGURE 6 ROTORCRAFT Role/Discipline Matrix

## National Facilities and Expertise

Maintaining modern aeronautical research and technology facilities and staff with superior technical skills is the core of NASA's role in developing technology for rotorcraft application. The rationale for

this activity is clear. Because of their complexity, rotorcraft are dependent on sub-scale and full-scale testing and, therefore, require elaborate wind tunnels and simulators. The Army maintains limited rotary-wing research facilities of its own; the Air Force is prohibited from helicopter development by a memorandum of understanding between the Chiefs of Staff signed in 1966; the Navy, for its part, does little rotor research. All things considered, NASA is the only agency with the major national facilities required.

The NASA in-house expertise in rotorcraft technology is currently at a low ebb because of transfers and retirements of personnel. Building up the staff to provide the necessary technical skills is essential. Fortunately, a competent core of Army research personnel working within the NASA organization significantly eases the problem.

The NASA aeronautical facilities to support the development of rotorcraft technology are, with some exceptions, superior to those available elsewhere in the world. A listing of the facilities is in Table 4. In a few functional areas, however, foreign facilities are more advanced. Two examples of this are the ONERA (Office National D' Etude et de Recherches Aerospatial, Chatillon, France) capability for icing research in the S-1 tunnel (25 ft, 290 knot capability) and the new Dutch-German wind tunnel (8 x 6 meter size with 110 meters/sec. speed). The latter has the added capability of low ambient noise and is the only tunnel in the world considered completely adequate for model studies, in reasonable scale, of quiet rotor designs to meet the proposed FAA regulation. Several European facilities also excel in their provisions for model set-up and quick-change, giving them a significant test productivity edge over comparable U.S. facilities.

TABLE 4 Facilities

- 40 × 80 Full Scale Tunnel
- V/STOL Tunnel
- Ground Based Simulation Facilities
- Flight Test Facilities
- Transonic Dynamics Tunnel
- 7 × 10 Low Speed Tunnel
- 7 × 10 High Speed Tunnel
- Variable Density Wind Tunnel
- Computer Facilities
- Instrumentation and Fabrication Facilities
- 6 × 28-inch Tunnel
- Low Turbulence Pressure Tunnel
- Structures and Fatigue Laboratory
- Structural Dynamics Laboratory
- Impact Dynamics Facility
- Data Acquisition and Reduction Facilities

In addition, there are a few unique capabilities that should be considered for development by NASA to meet some of the military and civil requirements for the decade of the 1980s. These capabilities could be developed either by establishing new facilities or by modifying existing ones. In any case, additional in-house personnel are

required. Such new facilities include:

- o A dedicated simulator for human factor research during rotorcraft approach and landing;
- o Rotorcraft icing test facilities for hover and forward flight testing; and
- o Better facilities for model and full-scale noise testing.

Propulsion facilities are available in industry, so, at this time, no additional NASA capability is required. The NASA propulsion facilities are well-suited to investigation of small gas turbine engines and components; however, they should be modernized.

The facilities made available to the Army under the joint Army-NASA agreement on aeronautical research are an integral part of the interagency cooperative plan, and these must continue to be available for Army use. The benefits realized by use of these facilities have been substantial; they have made major contributions to Army helicopter research and development programs.

## Research and Generic Technology Evolution

Basic Research and Generic Technology Evolution in aeronautics are clearly fundamental responsibilities of NASA. In the judgment of the panel, these responsibilities must be maintained and isolated from any pressures to increase down-stream work.

Again, the rationale is clear. Research and Generic Technology Evolution are the life blood of new ideas and fundamental advances, and NASA is the only agency in a position to undertake such work for the whole aeronautical community. Currently, the rotorcraft sector has not been able to take maximum advantage of NASA's basic and generic research capabilities partly because of the low level of NASA research on rotorcraft through the 1960s, and partly because of retirements of much of the in-house, helicopter-oriented NASA research talent. But the situation is slowly improving. The affiliation between NASA and the Army research organization is a major factor in developing a critical mass of personnel interested in rotor fundamentals.

Some typical areas of basic research in which NASA could play a significant role include computational aerodynamics, non-intrusive flow sensing, vortex-airfoil interaction, fundamental mechanisms of ice adherence and erosion susceptibility, high-temperature tribology, voice recognition, and materials with significant inherent damping. Areas to highlight are noted in Table 3.

## Vehicle Class Technology Evolution

The ability of NASA personnel to contribute to rotorcraft technology evolution has been greatly enhanced by their access to and interaction with Army personnel, which is fostered by the co-location of the NASA and Army Laboratories. This relationship between NASA and the largest free-world user of helicopters, assures a high degree

of relevance in NASA's work in rotorcraft technology evolution.

In the field of avionics, as it relates to communication and navigation, operational applications generally fall within the province of the FAA in cooperation with the avionics industry. Even so, there is a role for NASA in the field of advanced avionics technology development. NASA should continue to be in a position to do innovative work in this field without necessarily waiting for direction from the FAA.

A relentless forward movement of the cycle of knowledge and concept generation is imperative. The interruption of the cycle through the 1960s undoubtedly contributed to the erosion of U.S. leadership in commercial and military helicopters. With the build-up of research facilities that took place during the 1970s, NASA now has the opportunity and the capability to reverse the downward trend and to help the industry reestablish unchallenged world leadership.

## Technology Demonstration

NASA must continue to play an important role in demonstrating the feasibility of new component and system concepts. In rotorcraft, a technology demonstration usually must take place in a systems environment by flight test of research aircraft. Since rotorcraft technology is largely empirical, as new concepts of high potential benefit or depart from the rotorcraft experience base, the technical risk increases rapidly. While small-scale model tests and analyses can reduce this risk somewhat, the complexities and interrelationships of rotorcraft aerodynamics and structural dynamics are such that technology demonstration flight tests are of great value.

Some of NASA's most important contributions to aeronautics have been the result of flight testing research aircraft. These include the X-1, the first U.S. aircraft to explore supersonic flight systematically; the X-5, the first to flight test variable sweep wings; and the X-15, which extended manned flight to hypersonic speeds. All of these laid the technological foundation for the many successful U.S. supersonic aircraft that followed. In the rotorcraft field, the XV-1 compound, the VZ-2 tiltwing, and the XV-3 tiltrotor gave the U.S. an early technological lead in high-performance advanced configurations. Unfortunately, this work was not carried to a point where its feasibility could be clearly established.

More recently, two new technology demonstration rotorcraft, the ABC™ compound and the XV-15 tiltrotor, have extended the technology base for low disk-loading Vertical Takeoff or Landing (VTOL) with speed capabilities in the range of 300 knots. In a sense, these aircraft will perform the function for rotorcraft that the X series of aircraft performed for supersonic flight.

In propulsion, it is important to test engine assemblies in full scale. The testing of complete engine systems is a necessary supplement to the investigation of individual components such as compressor, combustor, turbine, and fuel controls because of the interactions among components. The Energy Efficient Engine ($E^3$) program is an excellent example of a NASA-sponsored propulsion technology demonstration program. A similar role is appropriate for NASA in rotorcraft propulsion.

In avionics, NASA can play an important role in the demonstration of advanced, low cost concepts and advanced technology systems such as satellite navigation--e.g., civil application of NAVSTAR Global Positioning System. With respect to aircraft operations, NASA fulfills an important role in support of the FAA, especially in demonstrating new concepts such as automatic approach techniques, since these involve both operating procedures and aircraft flight control. Another area in which NASA must take primary responsibility is in demonstrating active control technology and in assisting the FAA in the development of software validation procedures for digital fly-by-wire control systems.

## Technology Validation

In some situations, it may be important for NASA to manage large-scale ground or flight validation programs in order to provide the timely transfer of internationally competitive critical technology to industry. Because of the high inherent risk in any new rotorcraft technology, such programs deserve special attention. Validation programs, however, should be selected carefully. They should be clearly of national benefit and offer a major opportunity for high payoff. NASA should pursue only those programs that attract strong broadly based endorsement by industry or the FAA or the DOD. Prior to validation, the technology should have been demonstrated sufficiently, probably on a smaller scale.

The rationale for Technology Validation for rotorcraft is as follows. In the past, military programs have provided most of the technology needs of U.S. civil rotorcraft. However, future military rotorcraft design mission requirements are likely to be different in some important aspects from future civil requirements. Few, if any, of the military rotorcraft developments expected in the 1980s will provide timely, relevant technology for future civil applications. Without prior military validation, application of new technology could introduce excessively high risk, thus precluding application, especially if the cost of providing certification substantiation is high.

The most advanced technology available will be needed if the next generation of U.S. civil rotorcraft is to be competitive with aggressive government-supported foreign competition. Only those nations and companies that can supply superior rotorcraft economically will capture a significant share of the rotorcraft market of the 1980s and 1990s. Timely transfer to U.S. industry of critically needed proven technology is essential. Its respected technical competence, coupled with noncompetitive relationships with industries, the FAA, and the DOD, uniquely qualify NASA for the management of such programs.

Nothing in the current or proposed NASA rotorcraft program at this time appears to fall under the category of Technology Validation except some relatively small efforts on heavy-lift helicopter transmissions and on the service life of composite structures for rotorcraft. Candidates for validation programs include extension to rotorcraft of any of the benefits that can be derived from other related programs, such as the Large Composite Primary Aircraft Structures (LCPAS), the Materials for Advanced Turbine Engines (MATE), and the Engine Components Improvements (ECI) programs. A primary focus would be to provide

assistance to the first industry user in compiling the data necessary for FAA certification, assuming such assistance would produce the non-proprietary data needed by others to substantially ease subsequent certification efforts.

Another kind of possible validation program (though not necessarily recommended at this time) would be the development of size-sensitive component technology for future high speed concepts that have been demonstrated only in relatively small size and for large rotorcraft concepts that are significantly beyond the current design experience.

The panel agreed that validation programs should not draw away significant amounts of funds from the more essential programs that make up the Generic Technology Evolution, Vehicle Class Technology Evolution, and Technology Demonstration levels of NASA efforts. Such programs should not be permitted to divert key management attention from the NASA role in Research. Accordingly, separate organization within NASA aeronautics may be required to develop the necessary management skills and ensure the separation of funds and management devoted to technology validation efforts.

## Prototyping

The design, development, construction, and test of a rotorcraft engine or system sufficiently representative of a final product to serve as a production prototype is not a role that NASA should undertake. Should a special case arise of sufficient national importance to merit federal sponsorship of the development of a prototype rotorcraft, NASA's technical and managerial expertise should be considered. Such a program would be on an ad hoc basis.

## Operations Feasibility

With some exceptions, NASA's role in the field of Operations Feasibility is considered to be largely in support of the FAA or the DoD as tasks are assigned. The DoD and the FAA would assign certain tasks to NASA in order to take advantage of NASA's unique facilities, equipment and expertise. NASA, in addition, would be expected to initiate and place a high priority on operations feasibility tasks in the fields of aircraft systems, structures, materials, and human factors.

One rationale for a NASA role in the area of Operations Feasibility is that the unique rotorcraft configurations or concepts require operational validation. NASA has unparalleled capabilities in the research vehicles and facilities that are necessary to carry out such validation effectively. An example is the evaluation of the tiltrotor or the ABC™ in an operational environment. A technology demonstrator aircraft would afford the opportunity for experiments to determine how this new flight regime could best be applied to civil or military operations.

Although at this time NASA has no rotorcraft operations feasibility programs, the need for such programs could develop, particularly in the areas of exploration of high-speed vehicles such as the tiltrotor and ABC™ and investigation of new civil missions for heavy-lift vehicles.

## CONCLUSIONS AND RECOMMENDATIONS

The recommendations of the panel on NASA roles are summarized in Figure 6.

- o <u>Conclusion:</u> Rotorcraft have unique research facility requirements, and, because of the Army-NASA cooperative agreement, NASA is the only government agency currently franchised to develop such facilities for rotorcraft. During the 1970s, NASA did an excellent job of building up such facilities, though some specific additions still are required, particularly to reduce noise and rotor icing.
- o <u>Recommendation:</u> NASA should continue its present policy of assigning first priority to basic and generic research and to the continued upgrading and operation of its unique facilities. These basic aspects of the NASA program must not be compromised in the face of any expansion of NASA's role elsewhere. The importance of this role runs across all disciplines with the possible exception of that portion of avionics related to non-flight-control, because basic research on component technology is probably being addressed adequately by the communications industry. Still, there are such basic research areas as digital computer software architecture and validation techniques for flight control systems in which NASA has much to offer. In addition, development of new NASA wind tunnels for acoustic and icing work still requires attention.

- o <u>Conclusion:</u> NASA support of rotorcraft was significant in the 1950s, but minimal in the 1960s. This has undoubtedly been a factor in the recent weakening of the relative U.S. technical position in international markets for rotorcraft. In particular, the evolutionary bridge between generic research and rotorcraft demonstration has suffered.
- o <u>Recommendation:</u> In considering the expansion of NASA programs, high priority should be assigned to Generic and Vehicle Class Technology Evolution. This is true for all disciplines except in the communication and navigation aspects of avionics. The FAA should take prime responsibility in these areas. NASA

could have a unique contribution to make in such areas, however, in such specific fields as the extension of global positioning system technology to precision navigation and flight control of rotorcraft.

- Conclusion: Because of the complex and synergistic interaction of all disciplines in rotorcraft problems and because of the relative immaturity of the technical base, systems demonstration will continue to be a key role for any NASA rotorcraft program. Frequently, flight tests are the only way to verify rotorcraft research results and to demonstrate the practical outcome of development work. With its research vehicles and full-scale wind tunnel and modules, NASA has the facilities for the required program, though staffing has been inadequate to fully utilize them.
- Recommendation: NASA should continue to use Technology Demonstration programs as a focus for the output of Rotorcraft Technology Evolution, but NASA should reexamine its staffing with an eye toward filling the gaps. Here again NASA shares a role with the FAA, not only in the communications and guidance aspects of avionics, but also in any civil operating system demonstration.

- Conclusion: Operations Feasibility is really only a subset of Technology Demonstration. Whether or not it is a role for NASA depends upon whether interaction with the environment introduces significant uncertainty relating to the practicality or readiness of new technology.
- Recommendation: NASA should undertake Operational Feasibility work only when it is a key issue in the acceptance of a new concept and then only in close cooperation with and in support of the user. This is apt to be the case with unusual or unique aircraft system configurations when the ability to integrate efficiently into an operating scenario can be a critical factor in their feasbility. It is also possible to envision a supportive role for NASA in an operations feasibility demonstration of composite materials or technology in which human factors are critical.

- Conclusion: Technology Validation (risk reduction) can be particularly critical for rotorcraft because of their complexity and because of the difficulty in predicting size effects. As civil rotorcraft develop, their performance and operational requirements become less like those of military prototypes and consequently, the use of military prototypes for new technology risk reduction is becoming less useful. Some means of reducing the risk of incorporating and certifying new technology will be required if the U.S. industry is to compete in the civil market. A possible role for NASA in Technology Validation might be to support the industry by providing data for certification of new technology to the FAA for the first user. This would ease the task of certification for the other users that

follow. However, this should not be allowed to have a significant impact on NASA's basic research responsibilities.

- o Recommendation: NASA should undertake sizable Technology Validation programs only when:
  - The required funds can be made available without reduction in fundamental and applied research;
  - It is clear that NASA is the best agency for the task, particularly in light of heavy demands for project management; and,
  - There is a consensus as to the value and broad application of the results.

  The most likely area for NASA Technology Validation efforts is in the examination of the long-term environmental effects on composite structures, although there may be specific risks associated with electronic flight controls (fly-by-wire) and novel aircraft configurations in which risk reduction may be required beyond the first level of feasibility demonstration.

- o Conclusion: Industry must assume the risks of prototype development for the civilian market and, of course, the DOD must continue its normal practice of sponsoring prototype development of military equipment.
- o Recommendation: Prototyping of rotorcraft is not an appropriate role for NASA.

- o Conclusion: The rationale for government support of rotorcraft starts with the urgent need for technology for military superiority and includes the traditional arguments of economic benefit and balance of trade. Both areas are of growing concern because of an increasing military threat and a civil market that is expanding rapidly. But the rationale also can extend to include the significant societal benefits to be accrued through the use of rotorcraft, such as those related to disaster relief, emergency medical services, and other public services (police and fire work).
- o Recommendation: In examining opportunities for the most beneficial deployment of its resources, NASA should consider societal benefits as well as the military and civil markets in formulating and ranking the role it can play to support the development of a stronger rotorcraft technology base.

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# APPENDIX A

## DEFINITIONS OF ROLES AND DISCIPLINES

To facilitate the task undertaken by the participants in the ASEB workshop, a series of definitions of possible roles for NASA was developed. The roles represent steps in the hierarchy of the research and development process, beginning with a desire for knowledge and an understanding of basic phenomena, an idea, or technical concept, and ending with the design and construction of a vehicle, a vehicle component, or a new operational system.

### Definitions of Possible Roles for NASA

Each of the following eight roles as defined by NASA was reviewed by the participants, and the panels considered the extent to which NASA should carry out these roles.

#### National Facilities and Expertise

This category comprises the development and maintenance of test facilities, including wind tunnels, simulators, and computers, as well as the maintenance of personnel with specialized skills, technical knowledge, and expertise in the field of aeronautics.

#### Research

Programs in this category are designed to gain basic knowledge and understanding of physical phenomena and processes in all discipline areas relevant to aeronautics. The work is fundamental in character and is performed within NASA, at universities, in industry, and by independent research organizations.

#### Generic Technology Evolution

This category involves the pursuit of the results of specific lines of basic research that show promise of generating technology broadly applicable to a number of classes of vehicles. The work is evolutionary in nature and leads to the continued advancement of technology.

Such advances generally precede focused technology development in support of specific vehicle class needs. The work is conducted primarily within NASA, with appropriate university and industry support.

## Vehicle Class Technology Evolution

NASA programs in this category concentrate on specific vehicle classes and on the preparation of the unique technology data base required to improve the design and development of certain classes of aircraft. Activities include generating and evaluating new concepts and configuration approaches for the vehicle classes. Examples include V/STOL and supersonic cruise vehicles. In both cases, the technologies unique to those classes of aircraft are examined with regard to design feasibility, benefits, costs, etc. Then tailored data bases are developed.

## Technology Demonstration

This category includes programs that are conducted to demonstrate the technical feasibility of a technology advance or concept. Activities may include flight testing and component or systems demonstrations. Specific examples in the current NASA program are: Tilt-Rotor Research Aircraft, Energy Efficient Engine, Quiet Short-Haul Research Aircraft, and Terminal Configured Vehicle. Future modifications and tests on an aircraft to demonstrate the feasibility of Laminar Flow Control and flight tests of an Advanced Turboprop would be included in Technology Demonstration.

## Technology Validation

This comprises programs that include large-scale ground or flight validation as a necessary step to assure technology transfer. The purpose is to make possible, with minimal risk and without additional technology development, the practical utilization of high-benefit, high-risk conceptual, component, or subsystem technology advances. Specific examples in the present NASA program are: Composite Primary Aircraft Structure (CPAS), Materials for Advanced Turbine Engine (MATE), and Engine Component Improvement (ECI).

## Prototype Development

This category consists of design, development, construction, and testing of an aircraft, engine, or system that is sufficiently representative of a planned final product to serve as a production prototype. An example of such a program for the civil sector would be the supersonic transport (SST) program conducted by the FAA during the 1960s. Current NASA programs do not include any prototype developments, and none is currently planned.

## Operations Feasibility

This refers to operations conducted as research directed toward evaluating the feasibility or practicality of aircraft system operations to meet special needs or requirements or to demonstrate that a total, integrated operational system (e.g., new aircraft or simulated new aircraft, advanced integrated flight systems, approach and landing techniques, wake vortex alleviation, etc.) provides a service or benefit. The economic, environmental, and/or social aspects are considered.

# Definitions of Disciplines

## Aerodynamics

Aerodynamics is the science dealing with the motion of air and other gases and with the effects of such motion on objects moving through such media.

## Structures and Materials

This is the portion of aeronautical research and technology development dealing with the design of structures (the part of the aircraft, missiles and/or their components whose function is to carry loads in the broadest sense) and the materials used in aircraft and missile construction.

## Propulsion

This disciplinary heading includes the part of aeronautical research and technology development relating to the various methods and systems for generating and delivering power for propelling and/or lifting aircraft and missiles.

## Electronics and Avionics

Electronics refers to that aircraft and missile electrical equipment that is required for the basic operation of the vehicles--e.g., flight and engine controls. Avionics means the electrical equipment used for mission functions, such as air-to-ground communications and navigation. In military aircraft and missiles, the latter category includes offensive and defensive equipment and weapons control systems.

## Vehicle Operations

This area deals directly with operational problems encountered by aircraft and missiles, such as icing, detection and dissemination of weather information, and air traffic control systems.

## Human Engineering

This discipline addresses the study of human capabilities and problems that occur at the interfaces between the crew and the aircraft. It includes work on and use of simulators, crew work-load studies, and studies of the optimization of cockpit instrumentation and controls.

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